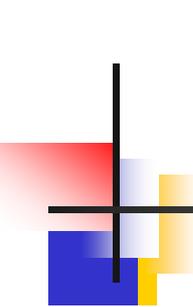


# Advanced topics in databases – Multimedia Databases

---

V. Megalooikonomou  
XML

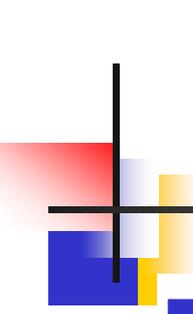
(based on slides by Silberschatz, Korth and Sudarshan at Bell Labs and  
Indian Institute of Technology)



# General Overview - XML

---

- **Introduction**
- Motivation
- Structure of XML data
- XML document schema
- Querying and transformation
- Application Program Interface
- Storage of XML data
- XML applications



# Introduction

---

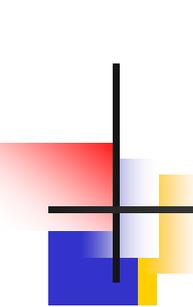
- XML: Extensible Markup Language
- Defined by the WWW Consortium (W3C)
- Originally intended as a document markup language not a database language
  - Documents have tags giving extra information about sections of the document
    - E.g. `<title> XML </title>` `<slide> Introduction ...</slide>`
  - Derived from SGML (Standard Generalized Markup Language), but simpler to use than SGML
  - **Extensible**, unlike HTML it does not prescribe the set of tags allowed
    - Users can add new tags, and *separately* specify how the tag should be handled for display
  - Goal was to replace HTML as the language for publishing documents on the Web

# XML Introduction (Cont.)

The ability to specify new tags, and to create nested tag structures made XML a great way to exchange **data**, not just documents.

- Much of the use of XML has been in data exchange applications, not as a replacement for HTML
- Tags make data (relatively) *self-documenting*
  - E.g.

```
<bank>
  <account>
    <account-number> A-101    </account-number>
    <branch-name>      Downtown </branch-name>
    <balance>         500      </balance>
  </account>
  <depositor>
    <account-number> A-101    </account-number>
    <customer-name> Johnson </customer-name>
  </depositor>
</bank>
```



# XML Introduction (Cont.)

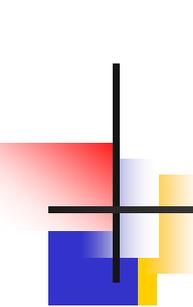
---

- **Disadvantage:**

- Storage – XML is inefficient since tag names are repeated throughout the document

- **Advantages:**

- Makes the message self-documenting
- The format is not rigid. It allows the format of the data to evolve over time.
- XML format is widely accepted, so, a wide variety of tools are available



# General Overview - XML

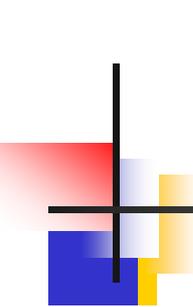
---

- Introduction
- **Motivation**
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# XML: Motivation

Data interchange is critical in today's networked world

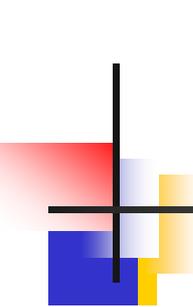
- Examples:
  - Banking: funds transfer
  - Order processing (especially inter-company orders)
  - Scientific data
    - Chemistry: ChemML, ...
    - Genetics: BSML (Bio-Sequence Markup Language), ...
- Paper flow of information between organizations is being replaced by **electronic flow of information**
- Each application area has its own set of standards for representing information
- XML has become the basis for all new generation data interchange formats



# XML Motivation (Cont.)

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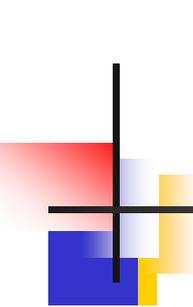
- Earlier generation formats were based on plain text with line headers indicating the meaning of fields
  - Similar in concept to email headers
  - Does not allow for nested structures, no standard “type” language
  - Tied too closely to low level document structure (lines, spaces, etc)



# XML Motivation (Cont.)

---

- Each XML based standard defines what are valid elements, using
  - XML type specification languages to specify the syntax
    - DTD (Document Type Descriptors)
    - XML Schema
  - Plus textual descriptions of the semantics
- XML allows new tags to be defined as required
  - However, this may be constrained by DTDs
- A wide variety of tools is available for parsing, browsing and querying XML documents/data



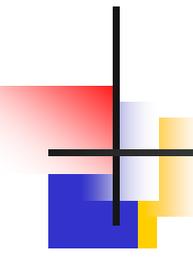
# General Overview - XML

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- Introduction
- Motivation
- **Structure of XML data**
- XML document schema
- Querying and transformation
- Application Program Interface
- Storage of XML data
- XML applications

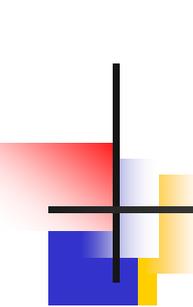
# Structure of XML Data

- **Tag**: label for a section of data
- **Element**: section of data beginning with `<tagname>` and ending with matching `</tagname>`
- Elements must be properly **nested**
  - Proper nesting
    - `<account> ... <balance> .... </balance> </account>`
  - Improper nesting
    - `<account> ... <balance> .... </account> </balance>`
  - Formally: every start tag must have a unique matching end tag, that is in the context of the same parent element.
- Every document must have a single top-level element



# Example of Nested Elements

```
<bank-1 >
  <customer >
    <customer-name > Hayes </customer-name >
    <customer-street > Main </customer-street >
    <customer-city > Harrison </customer-city >
    <account >
      <account-number > A-102 </account-number >
      <branch-name > Perryridge </branch-name >
      <balance > 400 </balance >
    </account >
    <account >
      ...
    </account >
  </customer >
  .
  .
</bank-1 >
```



# Motivation for Nesting

---

- Nesting of data is useful in data transfer
  - Example: elements representing customer-id, customer name, and address nested within an order element
- Nesting is not supported, or discouraged, in relational databases
  - With multiple orders, customer name and address are stored redundantly
  - normalization replaces nested structures in each order by foreign key into table storing customer name and address information
  - Nesting is supported in object-relational databases
- But nesting is *appropriate when transferring data*
  - External application does not have direct access to data referenced by a foreign key

# Structure of XML Data (Cont.)

- Mixture of *text* with *sub-elements* is legal in XML.

- Example:

```
<account>
```

```
  This account is seldom used any more.
```

```
  <account-number> A-102</account-number>
```

```
  <branch-name> Perryridge</branch-name>
```

```
  <balance>400 </balance>
```

```
</account>
```

- Useful for document markup, but discouraged for data representation

# Attributes

- Elements can have **attributes**

- ```
<account acct-type = "checking" >  
  <account-number> A-102 </account-number>  
  <branch-name> Perryridge </branch-name>  
  <balance> 400 </balance>  
</account>
```

- Attributes are specified by *name=value* pairs inside the starting tag of an element
- An element may have several attributes, but each attribute name can only occur once
  - ```
<account acct-type = "checking" monthly-fee="5" >
```

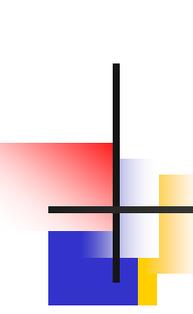
# Attributes Vs. Subelements

- Distinction between subelement and attribute
  - In the context of documents, **attributes** are part of markup, while **subelement contents** are part of the basic document contents
  - In the context of data representation, the difference is unclear and may be confusing
    - Same information can be represented in two ways
      - `<account account-number = "A-101"> ... </account>`
      - `<account>`  
`<account-number>A-101</account-number> ...`  
`</account>`
  - Suggestion: use attributes for identifiers of elements, and use subelements for contents

# More on XML Syntax

- Elements without subelements or text content can be abbreviated by ending the start tag with a `</>` and deleting the end tag
  - `<account number="A-101" branch="Perryridge" balance="200 />`
- To store string data that may contain tags, **without the tags being interpreted as subelements**, use CDATA as below
  - `<![CDATA[<account> ... </account>]]>`
    - Here, `<account>` and `</account>` are treated as just strings

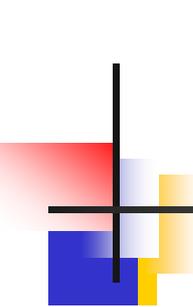
# Namespaces



- XML data has to be exchanged between organizations
- Same tag name may have different meaning in different organizations, causing confusion on exchanged documents
- Specifying a unique string as an element name avoids confusion
- Better solution: use **unique-name:element-name**
- Avoid using long unique names all over document by using XML Namespaces

# Namespaces

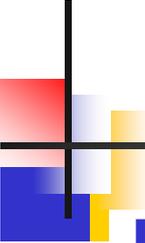
- `<bank xmlns:FB='http://www.FirstBank.com'>`  
    `<FB:branch>`  
        `<FB:branchname>Downtown</FB:branchname>`  
        `<FB:branchcity> Brooklyn</FB:branchcity>`  
    `</FB:branch>`  
`</bank>`



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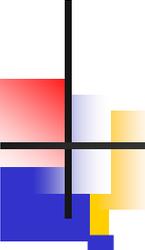
# XML Document Schema

---

- Database schemas constrain what information can be stored, and the data types of stored values
- XML documents are not required to have an associated schema
- However, schemas are very important for XML data exchange – Why?

# XML Document Schema

- Database schemas constrain what information can be stored, and the data types of stored values
- XML documents are not required to have an associated schema
- However, schemas are very important for XML data exchange – Why?
  - Otherwise, a site cannot automatically interpret data received from another site
- Two mechanisms for specifying XML schema
  - **Document Type Definition (DTD)**
    - Widely used
  - **XML Schema**
    - Newer, not yet widely used



# Document Type Definition (DTD)

---

- The type of an XML document can be specified using a DTD
- DTD constraints structure of XML data
  - What elements can occur
  - What attributes can/must an element have
  - What subelements can/must occur inside each element, and how many times.
- DTD does not constrain data types
  - All values represented as strings in XML
- DTD syntax
  - `<!ELEMENT element (subelements-specification) >`
  - `<!ATTLIST element (attributes) >`

# Element Specification in DTD

- Subelements can be specified as
  - names of elements, or
  - #PCDATA (parsed character data), i.e., character strings
  - EMPTY (no subelements) or ANY (anything can be a subelement – no constraint – any subelement even those not mentioned in the DTD)
- Example

```
<! ELEMENT depositor (customer-name
account-number) >
  <! ELEMENT customer-name(#PCDATA) >
  <! ELEMENT account-number (#PCDATA) >
```

# Element Specification in DTD

- Subelement specification may have regular expressions

```
<!ELEMENT bank ( ( account | customer |  
depositor) + ) >
```

- Notation:

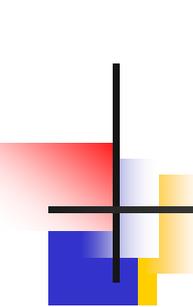
- "|" - alternatives
- "+" - 1 or more occurrences
- "\*" - 0 or more occurrences
- "?" - 0 or 1 occurrence

# Bank DTD

```
<!DOCTYPE bank [  
  <!ELEMENT bank ( ( account | customer |  
  depositor)+ ) >  
  <!ELEMENT account (account-number branch-name  
  balance) >  
  <! ELEMENT customer(customer-name customer-street  
  customer-city) >  
  <! ELEMENT depositor (customer-name account-  
  number) >  
  <! ELEMENT account-number (#PCDATA) >  
  <! ELEMENT branch-name (#PCDATA) >  
  <! ELEMENT balance(#PCDATA) >  
  <! ELEMENT customer-name(#PCDATA) >  
  <! ELEMENT customer-street(#PCDATA) >  
  <! ELEMENT customer-city(#PCDATA) >  
>
```

# Attribute Specification in DTD

- Attribute specification : for each attribute
  - Name
  - Type of attribute
    - CDATA
    - ID (identifier) or IDREF (ID reference) or IDREFS (multiple IDREFs)
      - more on this later
  - Whether
    - mandatory (#REQUIRED)
    - has a default value (value),
    - or neither (#IMPLIED)
- Examples
  - `<!ATTLIST account acct-type CDATA "checking" >`
  - `<!ATTLIST customer  
customer-id ID # REQUIRED  
accounts IDREFS # REQUIRED >`



# IDs and IDREFs

---

- An element can have at most one attribute of type ID
- The ID attribute value of each element in an XML document must be distinct
  - Thus the ID attribute value is an object identifier
- An attribute of type IDREF must contain the ID value of an element in the same document
- An attribute of type IDREFS contains a set of (0 or more) ID values. Each ID value must contain the ID value of an element in the same document

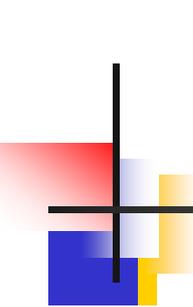
# Bank DTD with Attributes

- Bank DTD with ID and IDREF attribute types.

```
<!DOCTYPE bank-2[
  <!ELEMENT account (branch, balance)>
  <!ATTLIST account
    account-number ID          # REQUIRED
    owners          IDREFS # REQUIRED>
  <!ELEMENT customer(customer-name, customer-street,
customer-
city)>
  <!ATTLIST customer
    customer-id      ID          # REQUIRED
    accounts         IDREFS # REQUIRED>
  ... declarations for branch, balance, customer-name,
customer-street and customer-city
]>
```

# XML data with ID and IDREF attributes

```
<bank-2>
  <account account-number="A-401" owners="C100 C102">
    <branch-name> Downtown </branch-name>
    <branch>500 </balance>
  </account>
  <customer customer-id="C100" accounts="A-401">
    <customer-name>Joe</customer-name>
    <customer-street>Monroe</customer-street>
    <customer-city>Madison</customer-city>
  </customer>
  <customer customer-id="C102" accounts="A-401 A-402">
    <customer-name> Mary</customer-name>
    <customer-street> Erin</customer-street>
    <customer-city> Newark </customer-city>
  </customer>
</bank-2>
```



# Limitations of DTDs

---

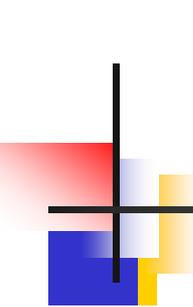
- No typing of text elements and attributes
  - All values are strings, no integers, reals, etc.
- Difficult to specify unordered sets of subelements
  - Order is usually irrelevant in databases
  - $(A | B)^*$  allows specification of an unordered set, but
    - Cannot ensure that each of A and B occurs only once
- IDs and IDREFs are untyped
  - The *owners* attribute of an account may contain a reference to another account, which is meaningless
    - *owners* attribute should ideally be constrained to refer to customer elements

# XML Schema

- XML Schema is a more sophisticated schema language which addresses the drawbacks of DTDs. Supports
  - Typing of values
    - E.g. integer, string, etc
    - Also, constraints on min/max values
  - User defined types
  - Is itself specified in XML syntax, unlike DTDs
    - More standard representation, but verbose
  - Is integrated with namespaces
  - Many more features
    - List types, uniqueness and foreign key constraints, inheritance
    - ..
- BUT: significantly more complicated than DTDs, not yet widely used.

# XML Schema Version of Bank DTD

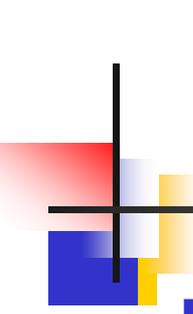
```
<xsd:schema xmlns:xsd=http://www.w3.org/2001/XMLSchema>
<xsd:element name="bank" type="BankType"/>
<xsd:element name="account" >
  <xsd:complexType>
    <xsd:sequence>
      <xsd:element name="account-number" type="xsd:string"/>
      <xsd:element name="branch-name" type="xsd:string"/>
      <xsd:element name="balance" type="xsd:decimal"/>
    </xsd:sequence>
  </xsd:complexType>
</xsd:element>
..... definitions of customer and depositor ....
<xsd:complexType name="BankType" >
  <xsd:sequence>
    <xsd:element ref="account" minOccurs="0"
      maxOccurs="unbounded"/>
    <xsd:element ref="customer" minOccurs="0"
      maxOccurs="unbounded"/>
    <xsd:element ref="depositor" minOccurs="0"
      maxOccurs="unbounded"/>
  </xsd:sequence>
</xsd:complexType>
</xsd:schema>
```



# General Overview - XML

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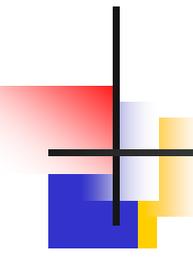
- Introduction
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# Querying and Transforming XML Data

---

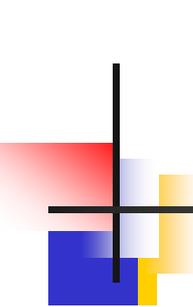
- Translation of information from one XML schema to another
- Querying on XML data
- Above two are closely related, and handled by the same tools
- Standard XML querying/translation languages
  - XPath
    - Simple language consisting of path expressions
  - XSLT
    - Simple language designed for translation from XML to XML and XML to HTML
  - XQuery
    - An XML query language with a rich set of features



# Querying and Transforming XML Data

---

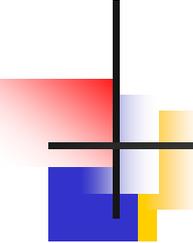
- Wide variety of other languages have been proposed, and some served as basis for the Xquery standard
  - XML-QL, Quilt, XQL, ...



# Tree Model of XML Data

---

- Query and transformation languages are based on a **tree model** of XML data
- An XML document is modeled as a tree, with **nodes** corresponding to elements and attributes
  - Element nodes have children nodes, which can be attributes or subelements
  - Text in an element is modeled as a text node child of the element
  - Children of a node are ordered according to their order in the XML document
  - Element and attribute nodes (except for the root node) have a single parent, which is an element node
  - The root node has a single child, which is the root element of the document



# Tree Model of XML Data

---

- We use the terminology of nodes, children, parent, siblings, ancestor, descendant, etc., which should be interpreted in the above tree model of XML data.

# XPath

- XPath is used to address (select) parts of documents using **path expressions**
- A path expression is a sequence of steps separated by "/"
  - Such as the file names in a directory hierarchy
- Result of path expression:
  - set of values that along with their containing elements/attributes match the specified path
- E.g. `/bank-2/customer/name` evaluated on the bank-2 data returns

```
<name>Joe</name>
<name>Mary</name>
```
- E.g. `/bank-2/customer/name/text( )` returns the same names, but without the enclosing tags

# XPath (Cont.)

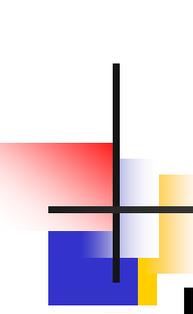
- The initial "/" denotes root of the document (above the top-level tag)
- Path expressions are evaluated left to right
  - Each step operates on the set of instances produced by the previous step
- Selection predicates may follow any step in a path, in [ ]
  - E.g. `/bank-2/account[balance > 400]`
    - returns account elements with a balance value greater than 400
    - `/bank-2/account[balance]` returns account elements containing a balance subelement

# XPath (Cont.)

- Attributes are accessed using "@"
  - E.g. `/bank-2/account[balance > 400]/@account-number`
    - returns the account numbers of those accounts with balance > 400
  - IDREF attributes are not dereferenced automatically (more on this later)

# Functions in XPath

- XPath provides several functions
  - The function `count()` at the end of a path counts the number of elements in the set generated by the path
    - E.g. `/bank-2/account[customer/count() > 2]`
      - Returns accounts with > 2 customers
    - Also function for testing position (1, 2, ..) of node w.r.t. siblings
  - Boolean connectives `and` and `or` and function `not()` can be used in predicates



# Functions in XPath

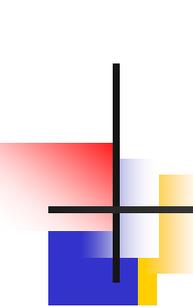
---

- IDREFs can be referenced using function `id()`
  - `id()` can also be applied to sets of references such as IDREFS and even to strings containing multiple references separated by blanks
  - E.g. `/bank-2/account/id(@owner)`
    - returns all customers referred to from the owners attribute of account elements.

# More XPath Features

Operator “|” used to implement union

- E.g. `/bank-2/account/id(@owner) | /bank-2/loan/id(@borrower)`
  - gives customers with either accounts or loans
  - However, “|” cannot be nested inside other operators.
- “//” can be used to skip multiple levels of nodes
  - E.g. `/bank-2//name`
    - finds any `name` element *anywhere* under the `/bank-2` element, regardless of the element in which it is contained (without full knowledge of the schema).
- A step in the path can go to:
  - parents, siblings, ancestors and descendantsof the nodes generated by the previous step, not just to the children
  - “//”, described above, is a short form for specifying “all descendants”
  - “..” specifies the parent.
  - We omit further details,



# XSLT

---

- A **stylesheet** stores formatting options for a document, usually separately from document
  - E.g. HTML style sheet may specify font colors and sizes for headings, etc.
- The **XML Stylesheet Language (XSL)** was originally designed for generating HTML from XML
- XSLT is a general-purpose transformation language
  - Can translate XML to XML, and XML to HTML
- XSLT transformations are expressed using rules called **templates**
  - Templates combine selection using XPath with construction of results

# XSLT Templates

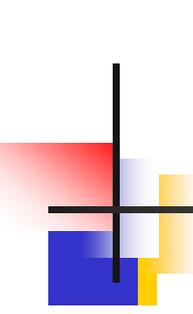
- Example of XSLT template with **match** and **select** part

```
<xsl:template match="/bank-2/customer" >  
  <xsl:value-of select="customer-name"/>  
</xsl:template >  
<xsl:template match="*" />
```

- The match attribute of xsl:template **specifies a pattern** in XPath
- Elements in the XML document matching the pattern are processed by the actions within the **xsl:template** element
  - **xsl:value-of** selects (outputs) specified values (here, customer-name)

# XSLT Templates

- For elements that do not match any template
  - Attributes and text contents are output as is
  - Templates are recursively applied on subelements
- The `<xsl:template match="*/>` template matches all elements that do not match any other template
  - Used to ensure that their contents do not get output.



# XSLT Templates (Cont.)

---

- If an element matches several templates, **only one is used**
  - Which one depends on a complex priority scheme/user-defined priorities
  - We assume only one template matches any element

# Creating XML Output

- Any text or tag in the XSL stylesheet that is not in the xsl namespace is output as is
- E.g. to wrap results in new XML elements.

```
<xsl:template match="/bank-2/customer" >
  <customer>
    <xsl:value-of select="customer-name"/>
  </customer>
</xsl:template>
<xsl:template match="*" />
```

- Example output:

```
<customer> John </customer>
<customer> Mary </customer>
```

# Creating XML Output (Cont.)

- Note: Cannot directly insert a `xsl:value-of` tag inside another tag
  - E.g. cannot create an attribute for `<customer>` in the previous example by directly using `xsl:value-of`
  - XSLT provides a construct `xsl:attribute` to handle this situation
    - `xsl:attribute` adds attribute to the preceding element
    - E.g. `<customer>`

```
<xsl:attribute name="customer-id">  
  <xsl:value-of select = "customer-id"/>  
</xsl:attribute>
```

results in output of the form

```
<customer customer-id="...."> ....
```
- `xsl:element` is used to create output elements with computed names

# Structural Recursion

- Action of a template can be to recursively apply templates to the contents of a matched element
- It constructs well-formed XML documents
- E.g.

```
<xsl:template match="/bank">
  <customers>
    <xsl:template apply-templates/>
  </customers >
<xsl:template match="/customer">
  <customer>
    <xsl:value-of select="customer-name"/>
  </customer>
</xsl:template>
<xsl:template match="*" />
```

- Example output:

```
<customers>
  <customer> John </customer>
  <customer> Mary </customer>
</customers>
```

# Joins in XSLT

- XSLT **keys** allow elements to be looked up (indexed) by values of subelements or attributes
  - Keys must be declared (with a name) and, the key() function can then be used for lookup. E.g.

- `<xsl:key name="acctno" match="account" use="account-number"/>`

- `<xsl:value-of select=key("acctno", "A-101")`

- Keys permit (some) joins to be expressed in XSLT

```
<xsl:key name="acctno" match="account" use="account-number"/>
```

```
<xsl:key name="custno" match="customer" use="customer-name"/>
```

```
<xsl:template match="depositor".
```

```
  <cust-acct>
```

```
    <xsl:value-of select=key("custno", "customer-name")/>
```

```
    <xsl:value-of select=key("acctno", "account-number")/>
```

```
  </cust-acct>
```

```
</xsl:template>
```

```
<xsl:template match="*" />
```

# Sorting in XSLT

Using an `xsl:sort` directive inside a template causes all elements matching the template to be sorted

- Sorting is done before applying other templates

■ E.g.

```
<xsl:template match="/bank">
  <xsl:apply-templates select="customer">
    <xsl:sort select="customer-name"/>
  </xsl:apply-templates>
</xsl:template>
<xsl:template match="customer">
  <customer>
    <xsl:value-of select="customer-name"/>
    <xsl:value-of select="customer-street"/>
    <xsl:value-of select="customer-city"/>
  </customer>
</xsl:template>
<xsl:template match="*" />
```

# XQuery

- XQuery is a general purpose query language for XML data
- Currently being standardized by the World Wide Web Consortium (W3C)
  - This description is based on a March 2001 draft of the standard. The final version may differ, but major features likely to stay unchanged.
- Alpha version of XQuery engine available free from Microsoft
- XQuery is derived from the Quilt query language, which itself borrows from SQL, XQL and XML-QL
- XQuery uses a

**for ... let ... where .. result ...**

syntax

**for** ⇔ SQL from

**where** ⇔ SQL where

**result** ⇔ SQL select

**let** allows temporary variables, and has no equivalent in SQL

# FLWR Syntax in XQuery

- The “for” clause uses XPath expressions, and variable in for clause ranges over values in the set returned by XPath
- Simple FLWR expression in XQuery
  - find all accounts with balance > 400, with each result enclosed in an <account-number> .. </account-number> tag

```
for    $x in /bank-2/account
let    $acctno := $x/@account-number
where  $x/balance > 400
return <account-number> $acctno </account-number>
```
- The “let” clause is not really needed in this query, and selection can be done in XPath. Query can be written as:

```
for $x in /bank-2/account[balance>400]
return <account-number> $X/@account-number
        </account-number>
```

# Path Expressions and Functions

- Path expressions are used to bind variables in the `for` clause, but can also be used in other places
  - E.g. path expressions can be used in **let** clause, to bind variables to results of path expressions
- The function **distinct( )** can be used to removed duplicates in path expression results
- The function **document(name)** returns root of named document
  - E.g. `document("bank-2.xml")/bank-2/account`
- Aggregate functions such as **sum( )** and **count( )** can be applied to path expression results
- XQuery does not support `groupby`, but the same effect can be got by nested queries, with nested FLWR expressions within a **result** clause
  - More on nested queries later

# Joins

- Joins are specified in a manner very similar to SQL

```
for $b in /bank/account,  
    $c in /bank/customer,  
    $d in /bank/depositor  
  
where $a/account-number = $d/account-number  
    and $c/customer-name = $d/customer-name  
return <cust-acct> $c $a </cust-acct>
```
- The same query can be expressed with the selections specified as XPath selections:

```
for $a in /bank/account  
    $c in /bank/customer  
    $d in /bank/depositor[  
        account-number =$a/account-number  
and  
        customer-name = $c/customer-name]  
return <cust-acct> $c $a</cust-acct>
```

# Changing Nesting Structure

- The following query converts data from the flat structure for **bank** information into the nested structure used in **bank-1**

```
<bank-1>
  for $c in /bank/customer
  return
    <customer>
      $c/*
      for $d in /bank/depositor[customer-name = $c/customer-
name],
        $a in /bank/account[account-number=$d/account-number]
      return $a
    </customer>
</bank-1>
```

- **\$c/\*** denotes all the children of the node to which **\$c** is bound, without the enclosing top-level tag

# XQuery Path Expressions

- `$c/text()` gives the text content of an element without any subelements/tags
- XQuery path expressions support the “->” operator for dereferencing IDREFs
  - Equivalent to the `id()` function of XPath, but simpler to use
  - Can be applied to a set of IDREFs to get a set of results
  - June 2001 version of standard has changed “->” to “=>”

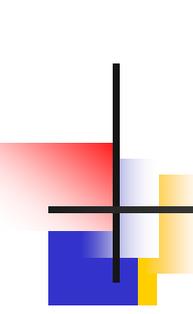
# Sorting in XQuery

- **Sortby** clause can be used at the end of any expression. E.g. to return customers sorted by name

```
for $c in /bank/customer  
return <customer> $c/* </customer> sortby(name)
```

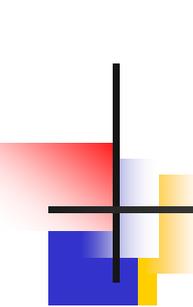
- Can sort at multiple levels of nesting (sort by customer-name, and by account-number within each customer)

```
<bank-1>  
for $c in /bank/customer  
return  
  <customer>  
    $c/*  
    for $d in /bank/depositor[customer-name=$c/customer-name],  
      $a in /bank/account[account-number=$d/account-number]  
    return <account> $a/* </account> sortby(account-number)  
  </customer> sortby(customer-name)  
</bank-1>
```



# Functions and Other XQuery Features

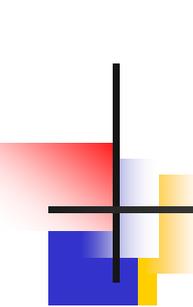
- User defined functions with the type system of XMLSchema  
**function** `balances(xsd:string $c) returns list(xsd:numeric) {`  
    **for** `$d in /bank/depositor[customer-name = $c],`  
        `$a in /bank/account[account-number=$d/account-number]`  
    **return** `$a/balance`  
}
- Types are optional for function parameters and return values
- Universal and existential quantification in “where” clause predicates
  - **some** `$e in path satisfies P`
  - **every** `$e in path satisfies P`
- XQuery also supports If-then-else clauses within “return” clauses



# General Overview - XML

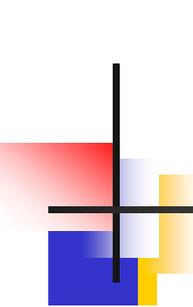
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- Introduction
- Motivation
- Structure of XML data
- XML document schema
- Querying and transformation
- **Application Program Interface**
- Storage of XML data
- XML applications



# Application Program Interface

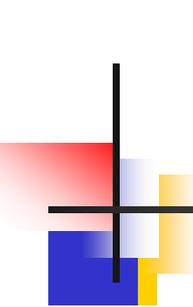
- There are two standard application program interfaces to XML data:
  - **SAX** (Simple API for XML)
    - Based on parser model, user provides event handlers for parsing events
      - E.g. start of element, end of element
      - Not suitable for database applications
  - **DOM** (Document Object Model)
    - **XML** data is parsed into a tree representation
    - Variety of functions provided for traversing the DOM tree
    - E.g.: Java DOM API provides Node class with methods
      - `getParentNode()`, `getFirstChild()`, `getNextSibling()`
      - `getAttribute()`, `getData()` (for text node)
      - `getElementsByTagName()`, ...
    - Also provides functions for updating DOM tree



# General Overview - XML

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- Introduction
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# Storage of XML Data

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- XML data can be stored in
  - Non-relational data stores
    - Flat files
      - Natural for storing XML
      - But has problems (no concurrency, no recovery, no integrity checks, no atomicity, no security...)
    - XML database
      - Database built specifically for storing XML data, supporting DOM model and declarative querying
      - XML is the basic data model
      - Currently no commercial-grade systems
  - Relational databases
    - Data must be translated into relational form
    - Advantage: mature database systems
    - Disadvantages: overhead of translating data and queries

# Storing XML in Relational Databases

## ■ Store as string

- E.g. store each top level element as a string field of a tuple in a database
  - Use a single relation to store all elements, or
  - Use a separate relation for each top-level element type
    - E.g. account, customer, depositor
    - Indexing:
      - Store values of subelements/attributes to be indexed, such as customer-name and account-number as extra fields of the relation, and build indices
      - Oracle 9 supports **function indices** which use the result of a function as the key value. Here, the function should return the value of the required subelement/attribute
- Benefits:
  - Can store any XML data even without DTD
  - As long as there are many top-level elements in a document, strings are small compared to full document, allowing faster access to individual elements.
- Q: Drawback ?

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  - As long as there are many top-level elements in a document, strings are small compared to full document, allowing faster access to individual elements.
- Q: Drawback ?
  - Need to parse strings to access values inside the elements; parsing is slow.

# Storing XML as Relations (Cont.)

- **Tree representation:** model XML data as tree and store using relations

*nodes(id, type, label, value)*  
*child (child-id, parent-id)*

- Each element/attribute is given a unique identifier
- Type indicates element/attribute
- Label specifies the tag name of the element/name of attribute
- Value is the text value of the element/attribute
- The relation *child* notes the parent-child relationships in the tree
  - Can add an extra attribute to *child* to record ordering of children
- Benefit: Can store any XML data, even without DTD
- Drawbacks?

# Storing XML as Relations (Cont.)

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- The relation *child* notes the parent-child relationships in the tree
  - Can add an extra attribute to *child* to record ordering of children
- Benefit: Can store any XML data, even without DTD
- **Drawbacks?**
  - Data is broken up into too many pieces, increasing space overheads
  - Even simple queries require a large number of joins, which can be slow

# Storing XML in Relations (Cont.)

## ■ Map to relations

- If DTD of document is known, can map data to relations
- Bottom-level elements and attributes are mapped to attributes of relations
- A relation is created for each element type
  - An id attribute to store a unique id for each element
  - All element attributes become relation attributes
  - All subelements that occur only once become attributes
    - For text-valued subelements, store the text as attribute value
    - For complex subelements, store the id of the subelement
  - Subelements that can occur multiple times represented in a separate table
    - Similar to handling of multivalued attributes when converting ER diagrams to tables
- Benefits:
  - Efficient storage
  - Can translate XML queries into SQL, execute efficiently, and then translate SQL results back to XML
- Drawbacks?

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    - Similar to handling of multivalued attributes when converting ER diagrams to tables
- Benefits:
  - Efficient storage
  - Can translate XML queries into SQL, execute efficiently, and then translate SQL results back to XML
- **Drawbacks?** Need to know DTD, translation overheads still present